Preparation of NSLS Beamline Bremsstrahlung Shielding Anamorphic Drawings

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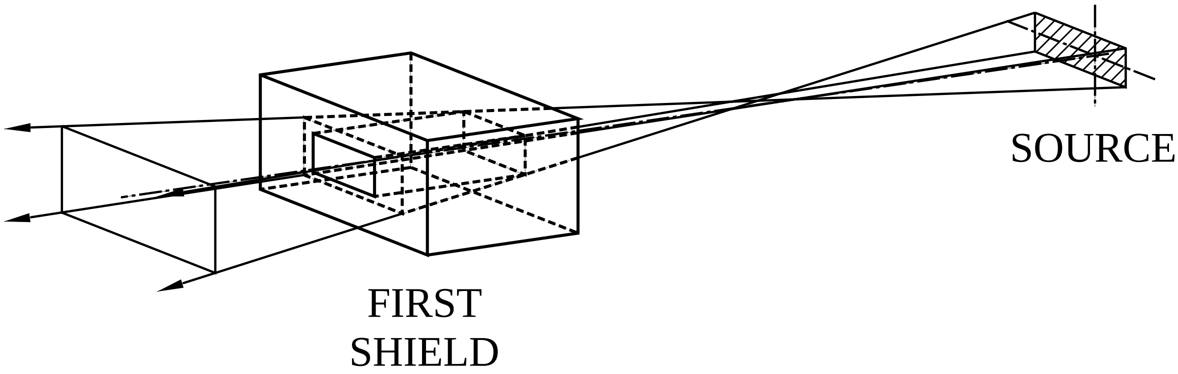
Introduction

PRM 1.3.5b describes the formal review required for each beamline, prior to operation at the NSLS. One purpose of the review is to assure that the beamline will operate safely with regard to radiation hazards. In this connection, bremsstrahlung shielding anamorphic drawings are important, and are a required part of the review.

These anamorphic drawings, i.e. drawings in which the two orthogonal scales are different, portray plan and elevation cross-sections of the beamline. Because the lengths of most beamlines greatly exceed their pertinent transverse dimension, an anamorphic drawing, which uses a reduced longitudinal scale, permits easy detailed visualization of the entire beamline on a single-sheet drawing. The drawing is used by the Beamline Review Committee to check the design of the shielding system, and by the Safety Officer at the beamline itself, to verify that the illustrated shielding system is indeed present. Indicated on the drawings are the extremum trajectories of bremsstrahlung γ rays, from a standardized model source located within the storage ring, to a series of absorbing shields in the beamline. The shields must meet certain dimensional requirements, in order to adequately attenuate the γ rays, and wherever the trajectories leave the confines of beampipes, mirror boxes, etc., "exclusion zones" must be erected to prevent personnel exposure. Finally, the drawings must provide a whole host of component identifiers and associated dimensions: enough to enable a re-drawing from numerical values and designated materials alone.

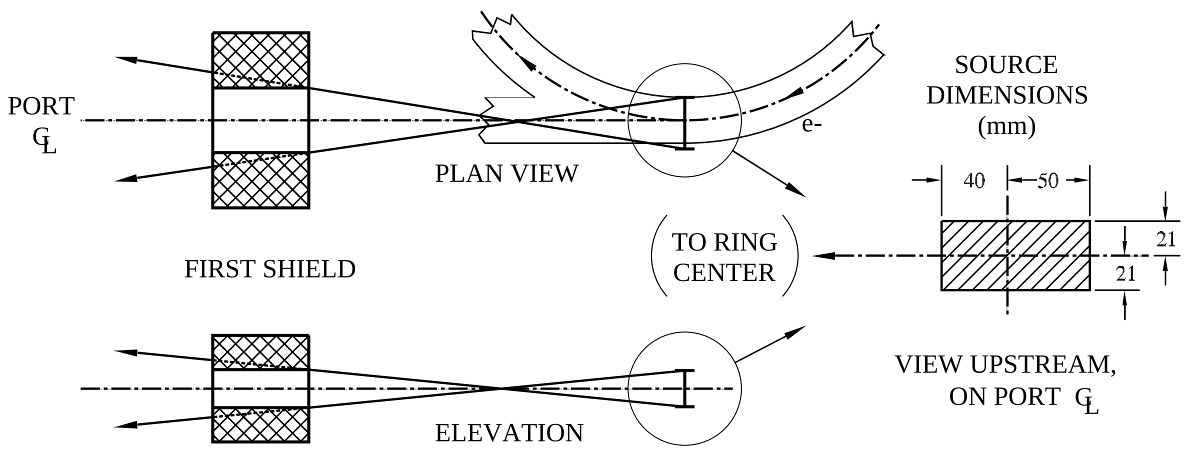
The Bremsstrahlung Source

Bremsstrahlung γ-rays are generated when the electrons in the stored beam interact with residual gas molecules in their path. Such interactions occur all around the ring. However, using additional information about the angular distribution of γ-rays and the possible trajectories of electrons stored in the ring, a prescription for a standardized model source can be generated, which is easily applied to the design of beamline shielding, and yet represents the worst-case bremsstrahlung accident as slightly more serious an event than it actually may be.



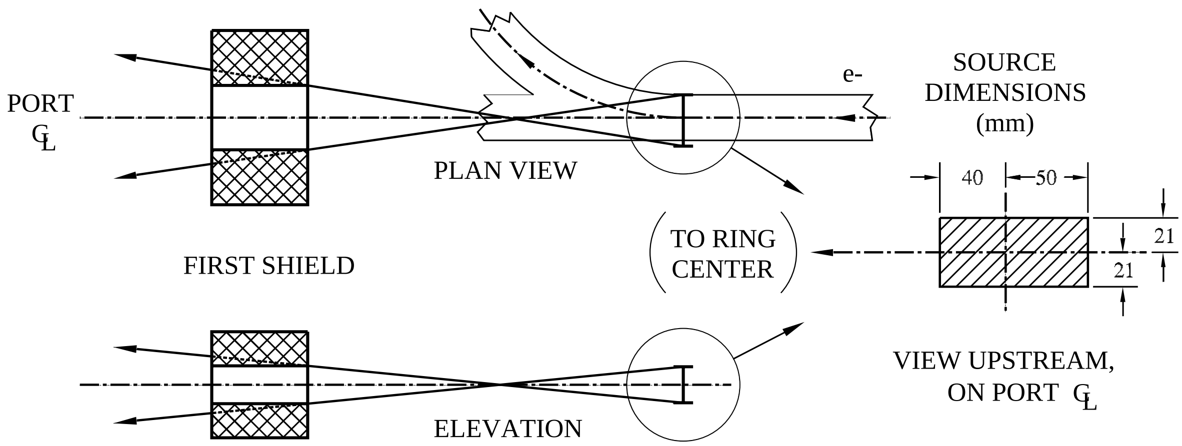
In general, the model source size and location are specified, but the angular divergence is obtained by assuming that the source radiates *isotropically* through the first beamline shield, i.e. the safety shutter shielding installed as part of the beamline front end. Bending magnet beam ports and insertion device ports use different model source geometries, as detailed below:

Bending Magnet Bremsstrahlung Model Source:



The model bremsstrahlung source is located at the synchrotron radiation source point for the beam port centerline. It is a planar source, oriented perpendicular to the port centerline, with dimensions illustrated above.

Insertion Device Bremsstrahlung Model Source:



For insertion device beamlines, the model bremsstrahlung source is not located in the insertion device at all, but rather in the entrance of the bend magnet downstream of the insertion device. The source is again planar, oriented perpendicular to the insertion device beam port centerline, and with dimensions given above.

Shield Dimensions:

Consider a single bremsstrahlung γ-ray which strikes the face of a large Pb shield at normal incidence. The original γ-ray interacts with the atoms in the shield to produce an electromagnetic cascade of electrons, positrons, more γ-rays, neutrons, etc. The cascade begins at the point of entry into the shield and extends into the depth of the shield. Also, as the cascade develops with depth into the shield, it spreads radially too. If the shield is *thick* enough and *wide* enough, the energy in the cascade eventually decreases, until no sign of it remains. The attenuation of the electromagnetic cascade as a function of depth into the shield is described using the "radiation length", X_o, of the shield material, while the radial attenuation is described by the "Molière length", X_m.

> *At the NSLS, Pb shields required against bremsstrahlung γ-rays must provide at least 203mm (8.00 inches) along the longitudinal path, and at least 50.8mm (2.00 inches) everywhere transverse to the path.*

This corresponds to 36.2 radiation lengths ($36.2X_o$) and 3.17 Molière lengths ($3.17X_m$), using the data tabulated in *Shielding Against High Energy Radiation*, Landolt-Börstein New Series, Group I, Volume 11, Springer-Verlag, New York, 1990, p. 223. Using additional data and formulas in this same reference, equivalent pure-element and composite shield dimensions can be calculated, e.g.:

Shielding equivalent to the standard NSLS Pb shield:

Material	Longitudinal Dimension	Transverse Dimension
Pb	203*mm* (8.00 inch)	50.8*mm* (2.00 inch)
U	115*mm* (4.51 inch)	32.9*mm* (1.26 inch)
MIL-T-21014, Type II, Class 4 Heavy Tungsten Alloy ("Heavimet Shield")	134*mm* (5.29 inch)	30.5*mm* (1.20 inch)

Making the Drawing:

We assume that the basic design of the beamline bremsstrahlung shielding has already been made. The design can be easily checked, once the anamorphic drawing is complete. The example drawing for a fictitious beamline, X-31A (see end of this report), presents illustrations for much of what is discussed below.

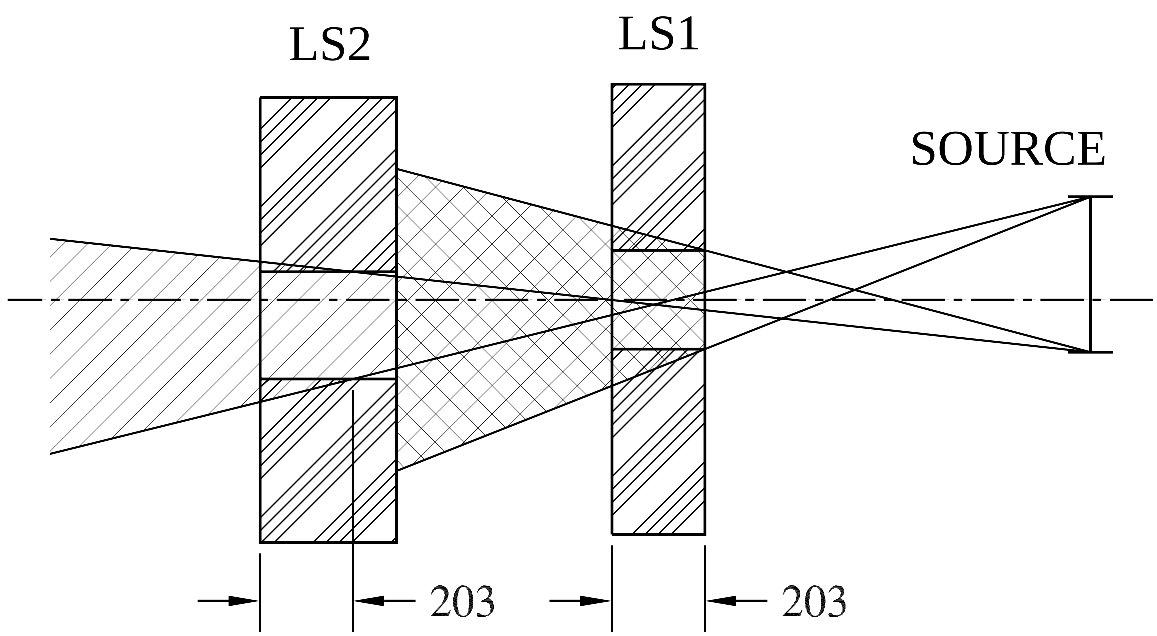
First, the drawing should represent the beamline as seen from its most-accessible side, that is, imagine standing at the downstream end of the beamline, facing toward the source. If the most-accessible side of the beamline is toward your right hand, then the drawing should place the bremsstrahlung source at the right hand edge of the sheet, and have the beamline extend downstream to the left-hand edge. (This is the case for the X-31A example drawing.) Otherwise, the source should be placed on the left, and the beamline extend downstream toward the right.

The drawing must have both plan and elevation views, which must be so identified. It should be drawn as a single sheet, on the largest available standard paper size, preferably Size 4 (668.8mm x 863.6mm [26.33" x 34.0"]) or Size 5 (863.6mm x 1118.6mm [34.0" x 44.0"]).

Once the paper size is chosen, the anamorphic scales can be determined. The beamline is portrayed from the bremsstrahlung source through the final bremsstrahlung shield. This may be only a fraction of the entire beamline, if optical systems (such as mirrors or a monochromator) deflect or offset the synchrotron radiation photon beam enough to separate it from the bremsstrahlung cone. In such a case, the bremsstrahlung can be stopped on a final shield placed in the midst of the beamline, rather than at its end (as is done for the X-31A example). Knowing the paper size and the source-to-final-shield distance, the longitudinal scale can be determined. The transverse scale, which is a horizontal distance on the plan view but a vertical distance on the elevation view, is then chosen so that the plan and elevation views comfortably fill the vertical size of the sheet (see the X31A example). Indicate the transverse and longitudinal scales on the drawing.

Now the actual drawing can begin. Lay out the beam port centerline and the branch beamline centerline for each view. The angle between the port centerline and the beamline centerline in the plan view should be indicated. Add the model bremsstrahlung source for both plan and elevation, and dimension it. Place the bremsstrahlung shields on the drawing, and label each with unique designations, consistent with labeling used in the beamline layout drawing (see X-31A example). Add an outline of the beam pipe for each view, up to the final bremsstrahlung shield. Include any hutches or concrete shield walls through which the beamline passes and identify them.

The heart of the anamorphic shielding drawing is the set of "extremal rays" associated with the shields. The first shield, in the beamline front end, defines the initial bremsstrahlung cone, and subsequent shields stop a portion of the cone, until the final shield stops any remainder. Generally two extremal rays are associated with each shield, in each view, and indicate the maximum extent of the remaining bremsstrahlung cone which must be dealt with at the subsequent shield. These rays originate from the model bremsstrahlung source, deviate from the beamline centerline by the maximal possible angle while also *just* passing through the specified longitudinal thickness of the

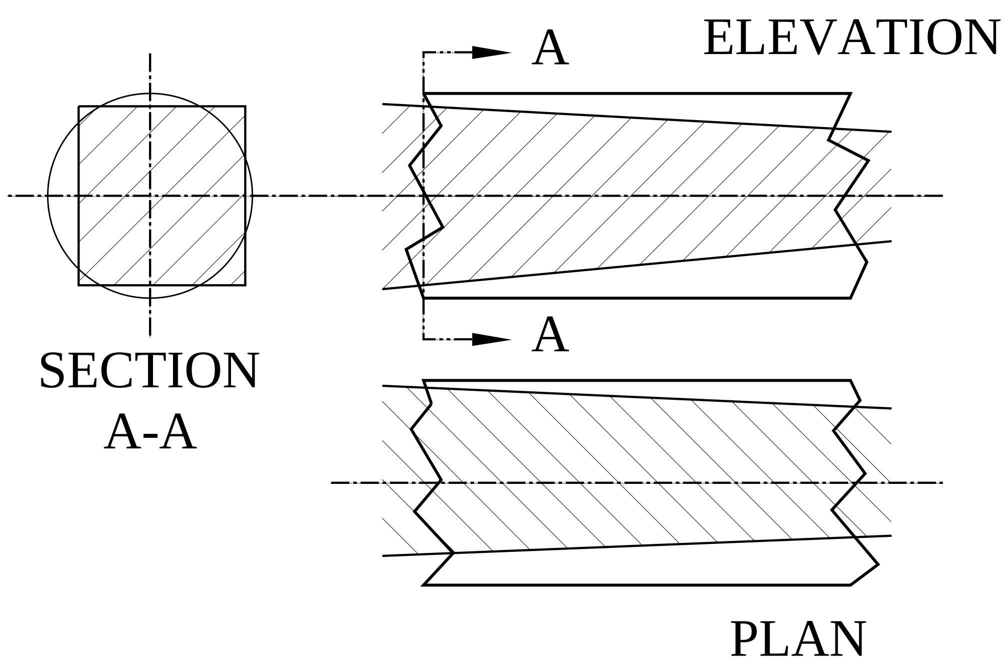


shield required to adequately attenuate a bremsstrahlung γ ray. This is illustrated below:
LS1 and LS2 are lead (Pb) shields, of at least the minimum necessary thickness (203mm). The rays drawn from the model source to the corners of the opening in LS1 are the extremal rays associated with LS1. They make a maximal angle with the beamline centerline by originating at one extreme end of the source and extending to the *opposite* extreme corner of the hole in LS1. Clearly, they pass through 203mm of Pb. (Note that the path length in the shield is greater than 203mm due to the angle of the ray from the centerline; but the difference is actually very small; the anamorphic scaling exaggerates the appearance.) However, consider what would happen if the angles made by these rays with the centerline were decreased slightly. Let the rays continue to originate at the extreme ends of the model source. The rays will now strike in the inside surface of the hole in LS1, and as a result, will *not* pass through 203mm of the shield. Therefore, γ rays on such a path will not be adequately attenuated, and must be dealt with by the subsequent shields. The double cross-hatched region represents the bremsstrahlung cone within the extremal rays from LS1, which must be dealt with by LS2 and subsequent shields, while the single-hatched region is the cone to be dealt with by subsequent shields alone. Note that LS2 is greater than 203mm thick. As a result, the extremal rays

extend from the extremes of the source to the *inside* of the opening in LS2, in such a way that they pass through 203mm of the shield. Other examples of extremal rays are found in the X-31A drawing.

Extremal rays for each shield should be added to the drawing.

Next, inspect the drawing to locate regions in which extremal rays leave the confines of the beampipe. Exclusion zones are required in these areas to prevent possible personnel exposure to bremsstrahlung γ rays. Exclusion zones are also often required just upstream of a shield, when the beampipe size is reduced to increase the effectiveness of the shield, but the length of this reduced-cross section pipe is longer than the shield. In addition, it is important to realize that because the bremsstrahlung cone is often rectangular in cross section, but round beampipes are used, exclusion zones may be required in regions in which the two standard views suggest that the cone is fully confined within the pipe. An example of this is given below:



Even though the plan and elevation views show the bremsstrahlung cone confined to the beampipe, Section A-A clearly indicates that it is not, and that an exclusion zone is required.

Locate all regions requiring exclusion zones, draw the exclusion zone and uniquely identify each with a label. (See X-31A example).

Now a whole host of dimensions must be added to the drawing. For the shields, overall dimensions must be given, i.e. horizontal width, vertical height, and longitudinal thickness. The location and dimensions of any holes in the shield must be specified. The distance of the shield from the model source must be given, together with the transverse location (both views) of the shield, relative to the beamline centerline. (Note: both shields and holes in shields are often centered about the beamline centerline. One can save effort, and make the drawing less cluttered by including the designation "centered" with the numerical value of a dimension [see X-31A], or by using a general note, such as "unless otherwise indicated, all dimensions crossing the beamline centerline are centered about it".)

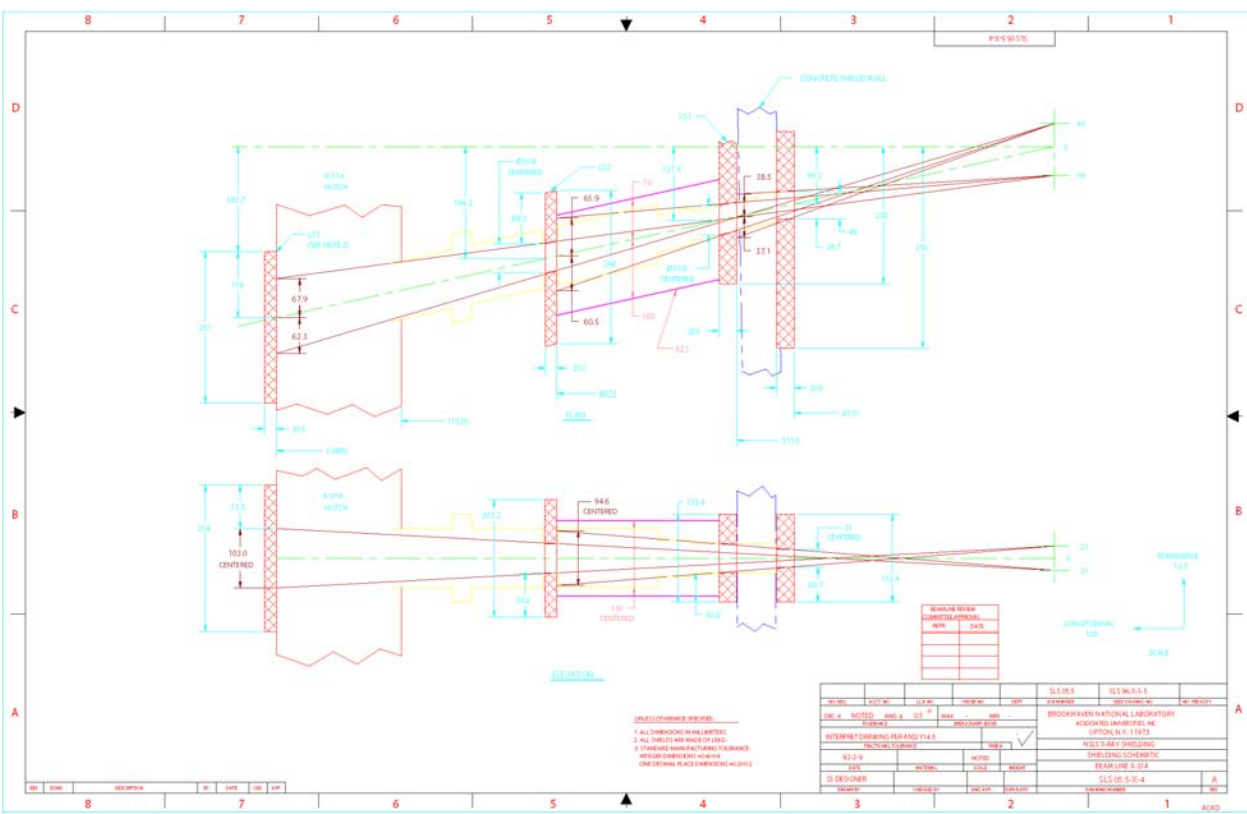
For exclusion zones, overall dimensions of the zone (width, height, and length) must be indicated, as well as the location of the zone on the beamline (one longitudinal and two transverse distances). For extremal rays, the location of the intersection point of each ray on a subsequent shield must be dimensioned. This makes it possible to determine whether all portions of the bremsstrahlung cone are stopped in an adequate longitudinal thickness of shielding material, with sufficient additional transverse shielding: e.g. 203mm of Pb longitudinal, and 50.8mm Pb transverse.

Finally, the material used in the shields must be specified, either shield-by-shield, or using a general note.
A checklist, which includes many of the topics previously discussed, is given below, and concludes this document.

<u>Sample X-Ray Beamline Anamorphic Schematic</u>

Please “Zoom In” to see more detail.

WARNING: Drawing not reproduced at original scale



CHECKLIST FOR NSLS BEAMLINE BREMSSTRAHLUNG
SHIELDING ANAMORPHIC DRAWINGS:

OK	**Not** OK	
		Illustrated from most-accessible side.
		Plan and elevation views, and identified.
		Large, single sheet.
		Transverse and longitudinal scales indicated.
		Angle to branch beamline centerline.
		Source dimensions, plan and elevation.
		Shields labeled.
		Beampipe outline indicated.
		Hutches and shield wall indicated and identified.
		Extremal rays indicated.
		Exclusion zones indicated and identified.
		Shield W, H, T.
		Shield hole locations and dimensions.
		Shield location L, H, V.
		Exclusion zone W, H, L.
		Exclusion zone location L, H, V.
		Extremal ray intersection points dimensioned.
		Adequate longitudinal and transverse shielding.
		Shield material.